BJT Amplifier for ECGR3131-001

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Figure 1 Simulated Common-Emitter Circuit

Abstract – The purpose of this project is to construct a BJT amplifier with a voltage gain of at least 10V and an output swing of no less than ±5V. Each group must find an amplifier circuit to achieve the specifications while using a 16V DC source. For this project, a common-emitter amplifier circuit was used in conjunction with resistor values at: 55k for R_1, 34k for R_2, 340 for R_D, and 50 for R_S. The gain of the circuit was calculated to be 282.76V/V, though the true gain during the live demonstration ended up at 152V/V. The most likely cause for the difference in gain between the theoretical and experimental results is that of noise produced by faulty or unoptimized potentiometers, or by faulty lab equipment. Despite the differences in results, the maximum gain of the demonstration still outperformed the original specifications for the project and maintained the appropriate output gain of ±10V.

Keywords – BJT, amplifier, common-emitter

I.   Introduction

For this project, a BJT amplifier to be constructed that achieved a voltage gain of at least 150V/V with a swing of ±10V and using a 16V voltage source. For these specifications, the common-emitter amplification circuit was chosen, as it offers the highest voltage gain out of the possible MOSFET amplification circuits.

II.   DC Analysis

Before starting the DC analysis, a simulation was performed using Multisim to determine the appropriate resistance ratios and values to achieve maximum gain for the circuit. In the simulation, the circuit was constructed using 4 potentiometers seen in the figure below. This change allowed for much easier testing with the biasing conditions of the circuit, and for adjusting the resistance without having to end the simulation.
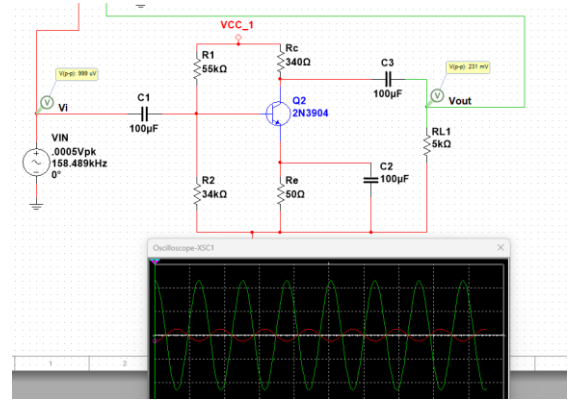
The simulation proved the following resistor values as optimal choices:

$$\frac{R_1}{R_2} = \frac{55k}{34k}\,\Omega, \frac{R_D}{R_S} = \frac{340}{50}\,\Omega$$

Once the resistor values were found, DC analysis was performed using the voltage divider technique for BJT biasing. As such, a 0V AC source was assumed, and so only the 16V source contributed to the calculations.
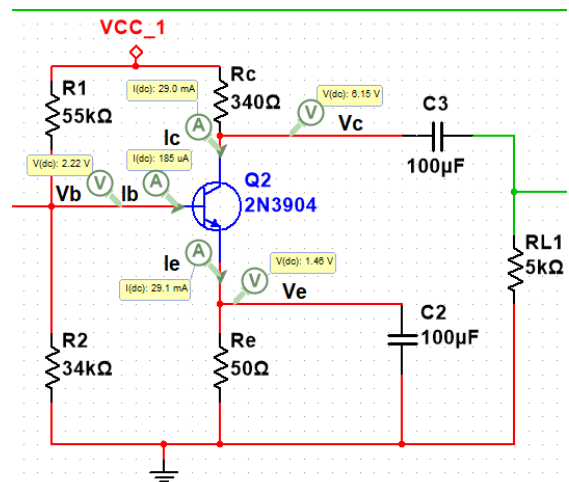

Figure 2 Common-Emitter Biasing Circuit

A Thevenin equivalent was created along the left side of the circuit to simplify the voltage and resistance to a single element each. The Thevenin equivalent components are:

$$V_{TH} = 16V \left(\frac{34k\Omega}{55k\Omega + 34k\Omega}\right) = 6.11V$$
$$R_{TH} = \left(\frac{55k\Omega * 34k\Omega}{55k\Omega + 34k\Omega}\right) = 21k\Omega$$

Using these values along with nodal analysis, a KCL equation for the bottom loop could be used to find the current for the base node I_B:

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

The equation for collector current $I_C = \beta I_B$ can be used to simplify the equation into terms of I_B:

$$V_{TH} = I_B R_{TH} + V_{BE} + I_B(\beta + 1)R_E$$

Beta is given by the model from Multisim, which is 416.4. V_{BE} is the voltage drop across the transistor, which in saturation is equivalent to 0.7V. The equation can therefore be solved:

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1)R_E} = 186\mu A$$

The earlier I_C and thus I_E equation now be solved using the value of I_B and the already defined value of beta, resulting in 29.1mA and 29.3mA respectively. As all of the necessary current values have been calculated, the remaining voltages can also be calculated using KCL:

$$V_B = V_{TH} - I_B R_{TH} = 2.214V$$
$$V_E = V_B - V_{BE} = 1.514V$$
$$V_C = V_{CC} - I_C R_C = 6.047V$$

III. AC Analysis

To perform AC analysis on the amplifier, a small signal equivalent was used equivalent. This circuit is split into two main parts: input and output characteristics. Using this model, finding the input and output impedances is much simpler.
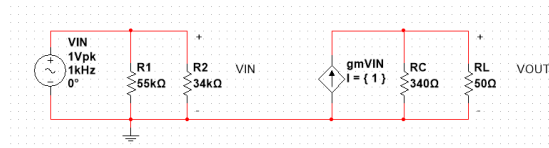

Figure 3 Small-Signal Biasing Circuit

The transconductance g_m can be calculated as $\frac{I_C}{26mV}$ which, using the values found during DC analysis, is equal to 232.58. Since $V_{GS} = V_{IN}$ during small-signal analysis, V_{OUT} can be characterized with the equation:

$$V_{OUT} = -g_m V_{IN} * (R_C||R_L)$$

Then by dividing the equation by V_{IN}, the gain can be calculated:

$$\frac{V_{OUT}}{V_{IN}} = -g_m * (R_D||R_L) = -282.76V/V$$

Input impedance can be found using the equation $r_{in} = R_{TH} \| R_\pi$. r_π can be calculated with $\frac{\beta}{g_m}$, and so when plugged into the impedance equation returns 175.017Ω. The output impedance r_{out} is similar, using the resistors $R_D\|R_L$, resulting in a value of 318.35Ω.

IV. Results

	Theoretical	Simulated	Experimental	Percent Error (%)
V_C (V)	6.047	6.155	7.6	23.4768
V_B (V)	2.214	2.219	2.072	6.6246
V_E (V)	1.514	1.457	1.465	0.5491
V_{CE} (V)	4.533	4.698	6.135	30.5875
I_B (μA)	0.000186	1.853E-04	1.41E-05	92.3799
I_C (μA)	0.0291	2.896E-02	2.87E-03	90.0898
I_E (μA)	0.0293	0.0291453	2.88E-03	90.1043

Table 1 Results of DC Analysis

Unfortunately, many of the calculated results greatly differed from the lab tests. This is most likely a result of faulty potentiometers. The potentiometers often had to be changed due to issues with noise or incorrect resistance values. Equally likely is faulty lab equipment, as other students encountered issues with the oscilloscope not reading correctly.

	Theoretical	Simulated	Experimental	Percent Error (%)
Max Gain (V/V)	282.76	231.600	152	86.0263
Rin (KOHM)	157.017	163.05	1580.6112	90.0661
Rin (KOHM)	157.017	163.05	1580.6112	89.3455

Table 2 Results of AC Analysis

Much of the same issues encountered during DC analysis were encountered during AC analysis as well, and so the same conclusions made during DC analysis must also be made here.
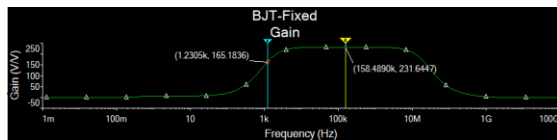
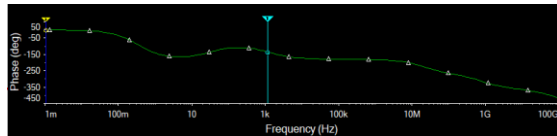*Figure 4 Simulated Gain vs. Frequency*
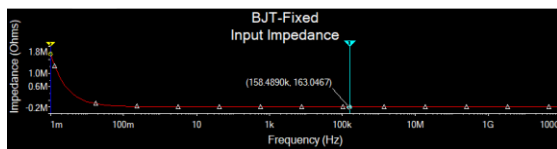

Figure 5 Simulated Phase vs. Frequency
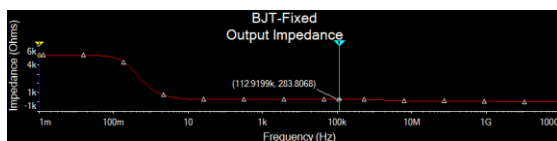

Figure 6 Simulated Input Impedance

Figure 7 Simulated Output Impedance

The change in impedance is related to the capacitors in the circuit, which operate at lower frequencies. As the frequency increases, the capacitor passes less and less current through the circuit, eventually acting as an open circuit. Though the capacitors due help with noise, this means that the circuit will be less effective at higher frequencies.

For the demonstration, the amplifier was constructed based off the simulated model and performed with a peak voltage gain of 152 volts/volt at an input of 12.5mV at 491kHz.
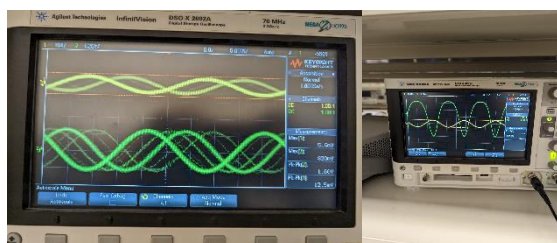

Figure 8 Demonstration of Gain (Left) and Swing (Right) for BJT Amplifier

The amplifier worked at frequencies between 5.1kHz and 480kHz, reaching its peak voltage gain at 9.9kHz. The signal becomes asymmetrical at 80mV. Had different resistors been used, a more stable signal could have likely been attained.

V.   Areas for Improvement

Unoptimized resistance values, along with faulty equipment, led to less than desirable results from the lab. If performed again, better care to resistance ratios would be maintained.

VI.   Conclusion

During the experiment, the best gain achieved during the simulation and through hand calculations was around 282.76V/V. However, the measured value was only capable of reaching 151V/V. While this is still a result that lands around the desired gain of ≥150V/V, better results could have been achieved using a different ratio of resistance values.

 The amplifier's output remains symmetrical up to 80mV. This is likely a result of the unoptimized resistor combinations used for the circuit, resulting in an imbalance in the resistance ratios and a loss of stability at higher voltages.

In designing the circuit, the most important aspect was determining the correct ratio of resistances to achieve the best possible gain for the amplifier. Everything else was built around these ratios and resistor combinations. As such, having an imbalance as proven by the gain and asymmetry of the output signal proves that much more could have been done in ensuring that the best possible resistors could have been found.